US009405922B2

(12) **United States Patent**
Schreiber et al.

(10) **Patent No.: US 9,405,922 B2**
(45) **Date of Patent: Aug. 2, 2016**

(54) **COMPUTER-IMPLEMENTED METHOD FOR ROLE DISCOVERY AND SIMPLIFICATION IN ACCESS CONTROL SYSTEMS**

(75) Inventors: **Robert S. Schreiber**, Palo Alto, CA (US); **William G. Horne**, Lawrenceville, NJ (US)

(73) Assignee: **Hewlett Packard Enterprise Development LP**, Houston, TX (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 2267 days.

(21) Appl. No.: **12/348,832**

(22) Filed: **Jan. 5, 2009**

(65) **Prior Publication Data**

US 2009/0144803 A1 Jun. 4, 2009

Related U.S. Application Data

(63) Continuation-in-part of application No. 11/888,381, filed on Jul. 31, 2007.

(51) **Int. Cl.**
G06F 21/00 (2013.01)
G06F 21/62 (2013.01)

(52) **U.S. Cl.**
CPC ***G06F 21/6218*** (2013.01); *G06F 2221/2141* (2013.01)

(58) **Field of Classification Search**
CPC G06F 21/31
USPC 713/182; 726/2, 3, 6
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

7,284,000	B2	10/2007	Kuehr-McLaren et al.	
2004/0243546	A1	12/2004	Mishra et al.	
2005/0138419	A1 *	6/2005	Gupta et al.	713/201
2005/0138420	A1	6/2005	Sampathkumar et al.	

OTHER PUBLICATIONS

Ene, Alina et al.; "Fast Exact and Heuristic Methods for Role Minimization Problems"; Jun. 2008; 1-10; Association for Computing Machinery; New York, NY, USA.

Mhand Hifi et al; A Neural Network for the Minumum set covering problem, Aug. 23, 2010, 11 Pages.

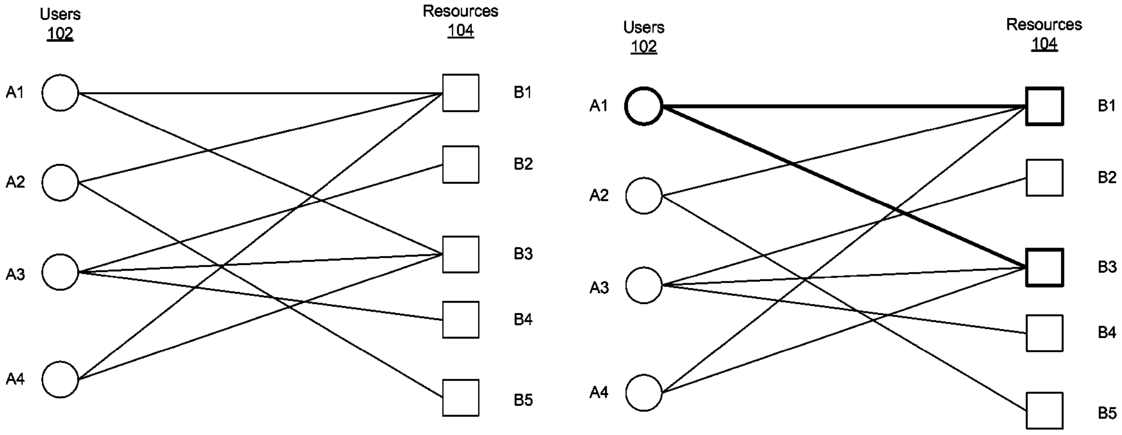
* cited by examiner

Primary Examiner — Christopher Brown
(74) *Attorney, Agent, or Firm* — Fabian VanCott

(57) **ABSTRACT**

A method includes selecting a first biclique role in a plurality of roles and finding all roles in the plurality that have a set of vertices of a second type that is a subset of a set of vertices of the second type in the first role; removing each of the subsets from the set of vertices of the second type corresponding to the first role; and reassigning the vertices of the first type to the roles such that original associations between the vertices of the first type and the vertices of the second type are maintained.

20 Claims, 18 Drawing Sheets



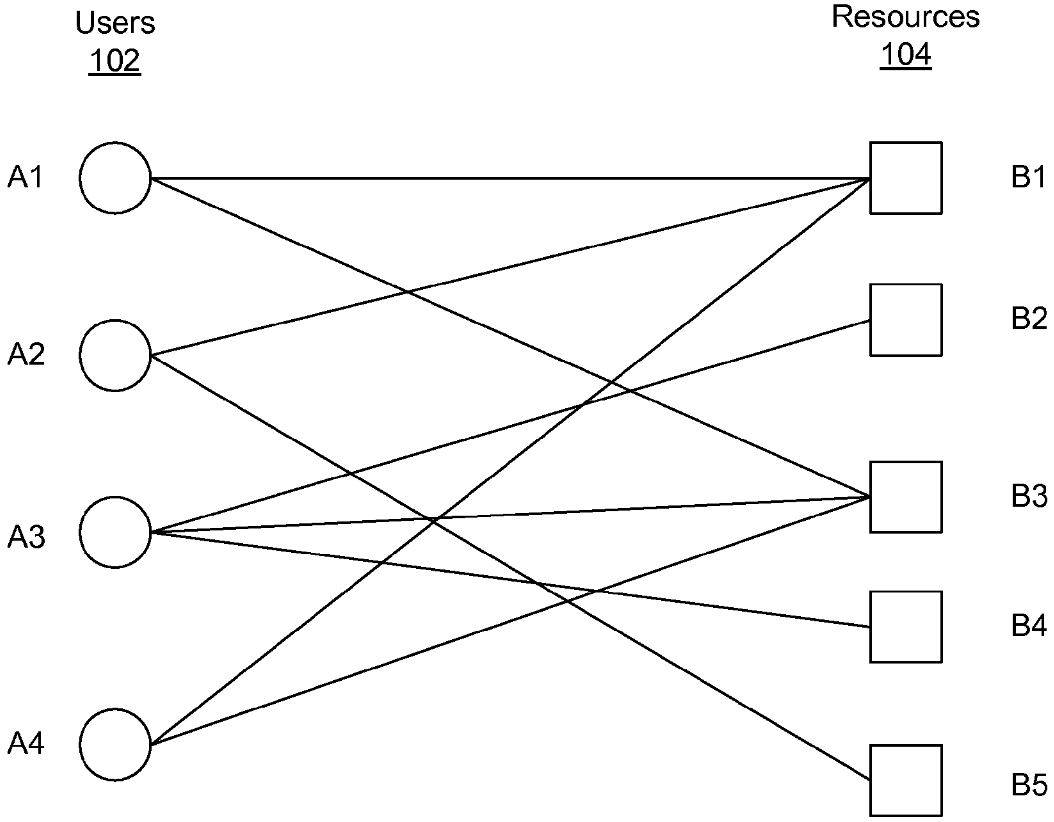


Fig. 1A

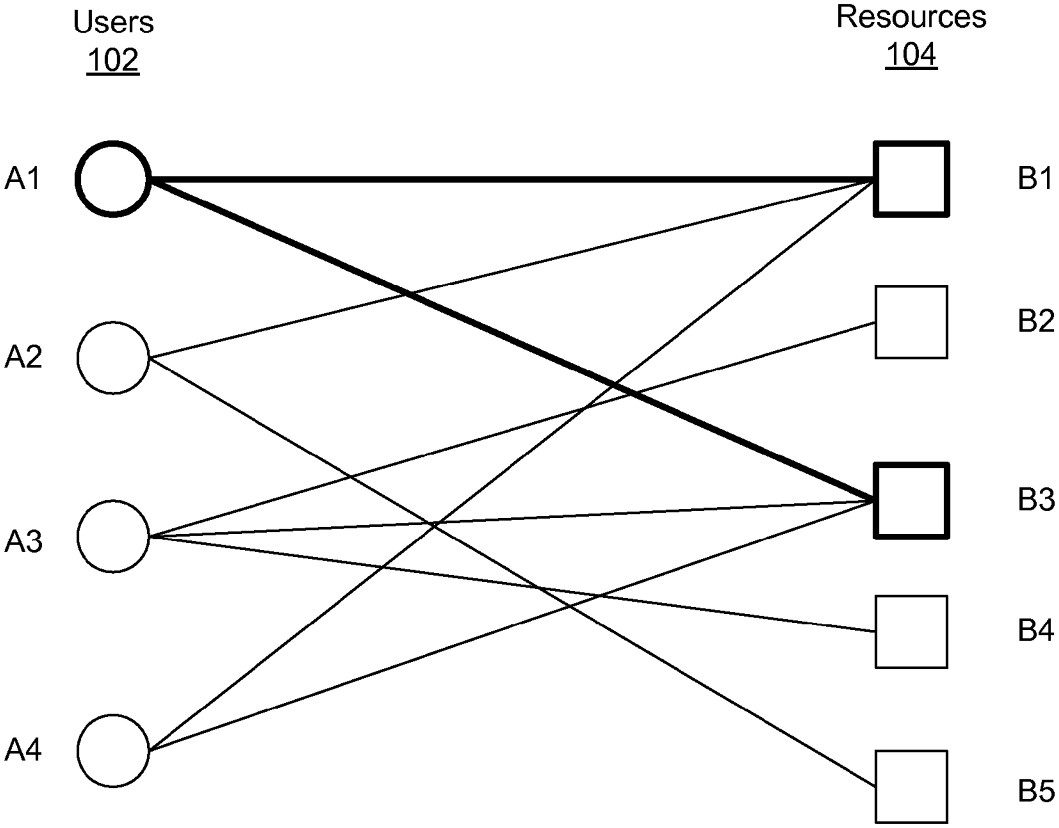


Fig. 1B

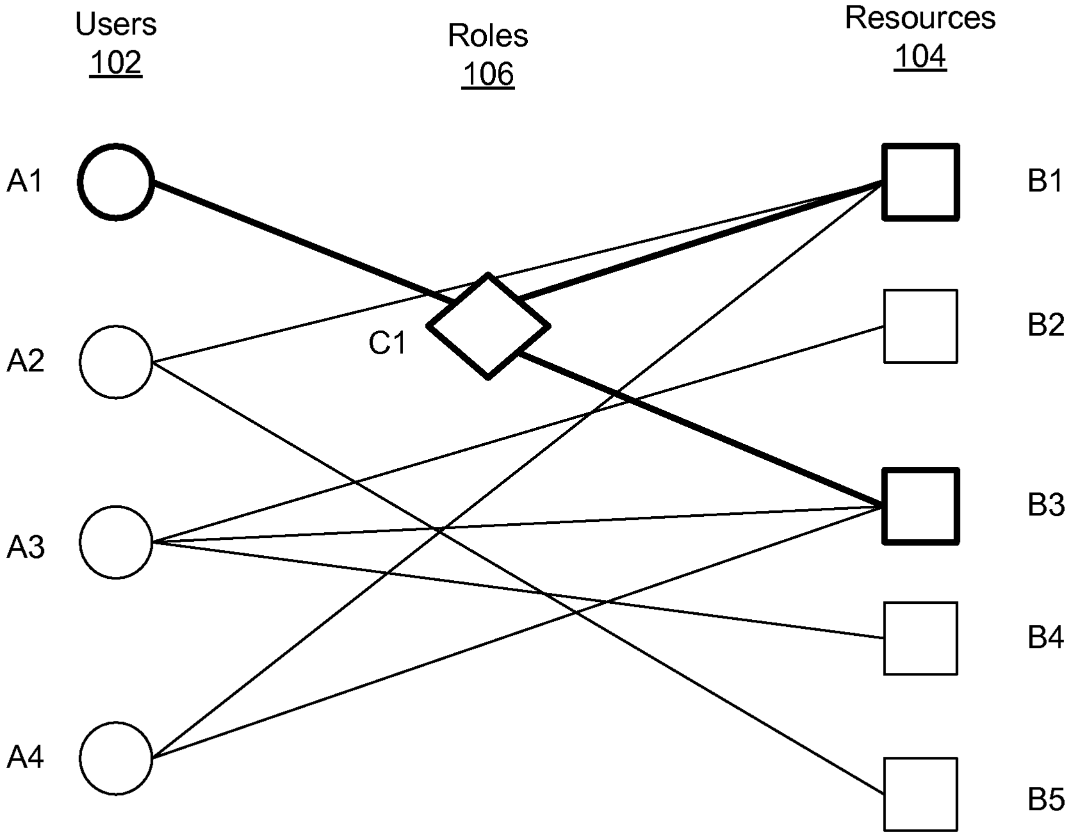


Fig. 1C

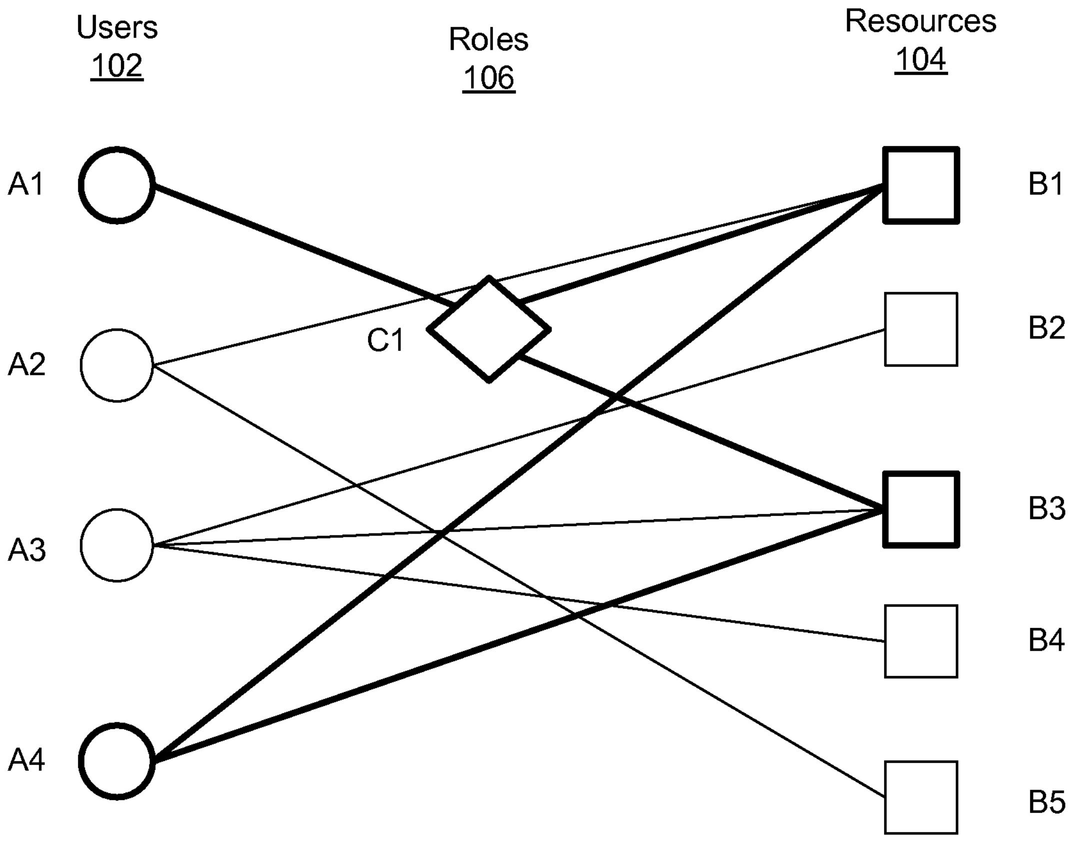


Fig. 1D

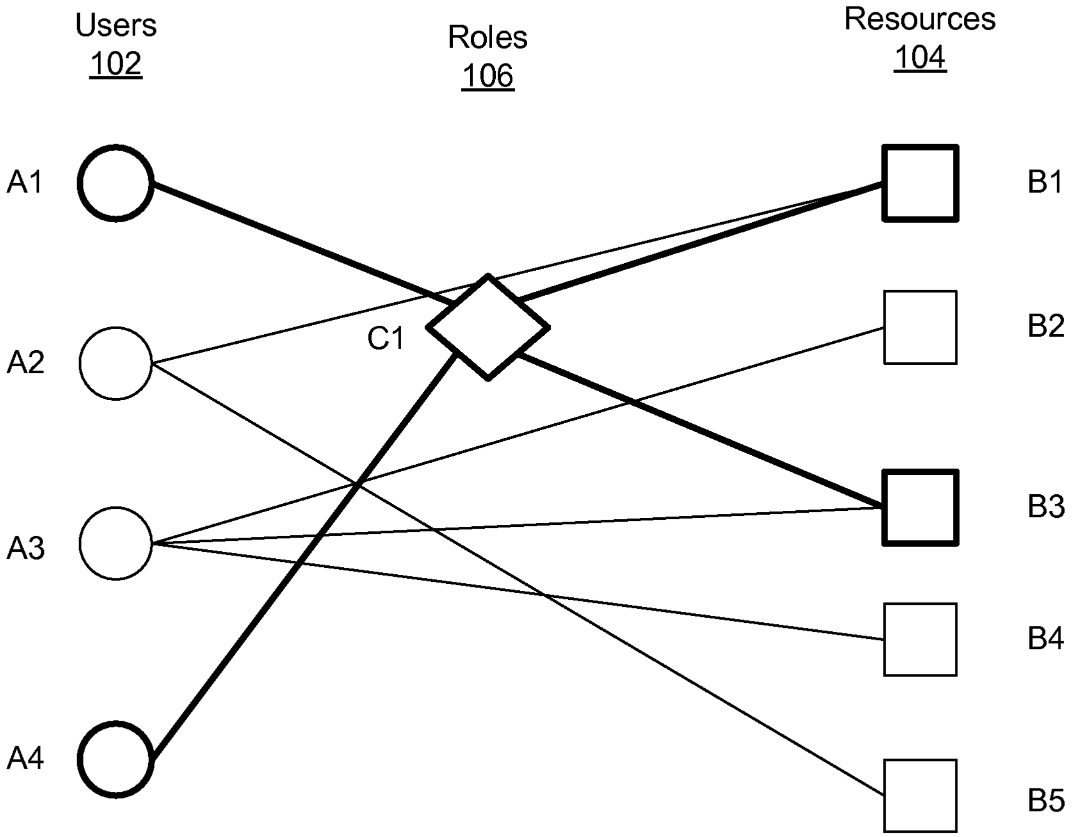


Fig. 1E

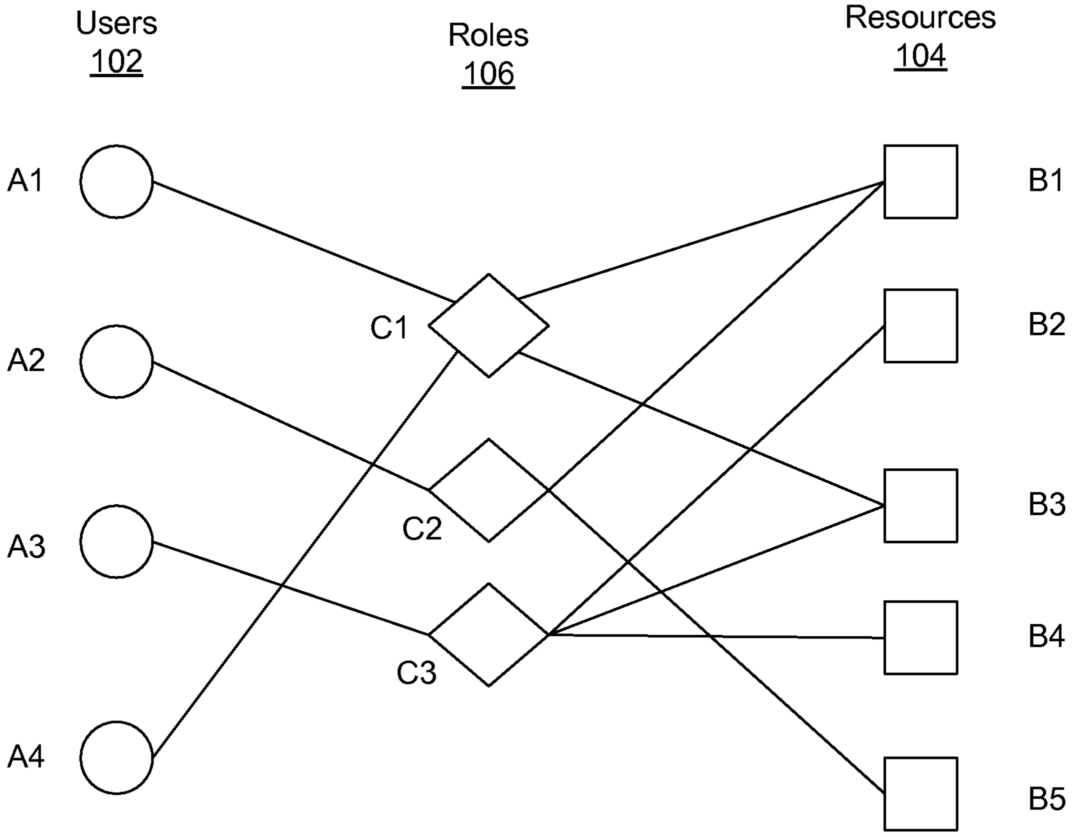

Users
102
Roles
106
Resources
104
A1
A2
A3
A4
C1
C2
C3
B1
B2
B3
B4
B5

Fig. 1F

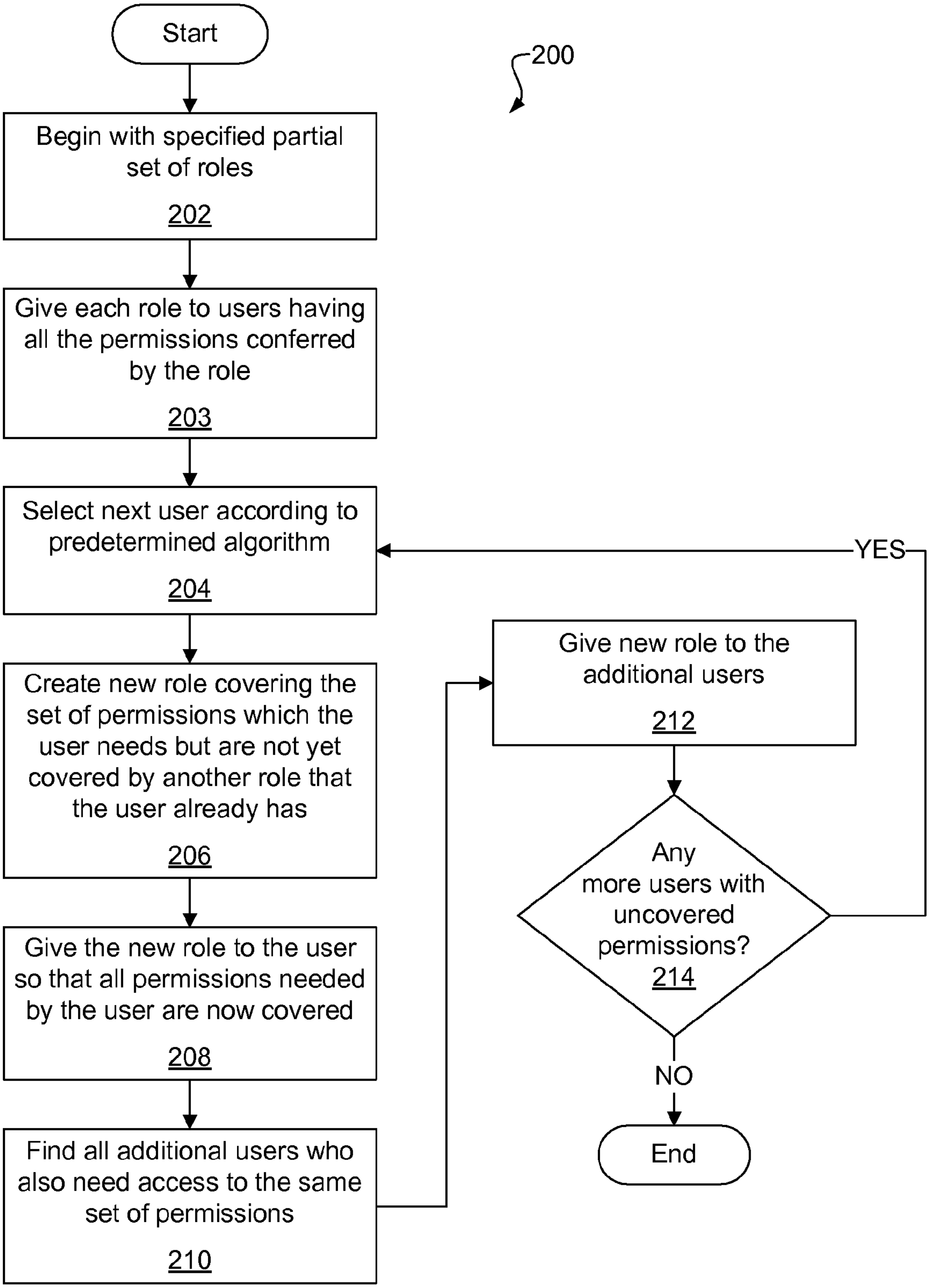

200
Start
Begin with specified partial set of roles
202
Give each role to users having all the permissions conferred by the role
203
Select next user according to predetermined algorithm
204
Create new role covering the set of permissions which the user needs but are not yet covered by another role that the user already has
206
Give the new role to the user so that all permissions needed by the user are now covered
208
Find all additional users who also need access to the same set of permissions
210
Give new role to the additional users
212
Any more users with uncovered permissions?
214
YES
NO
End

Fig. 2A

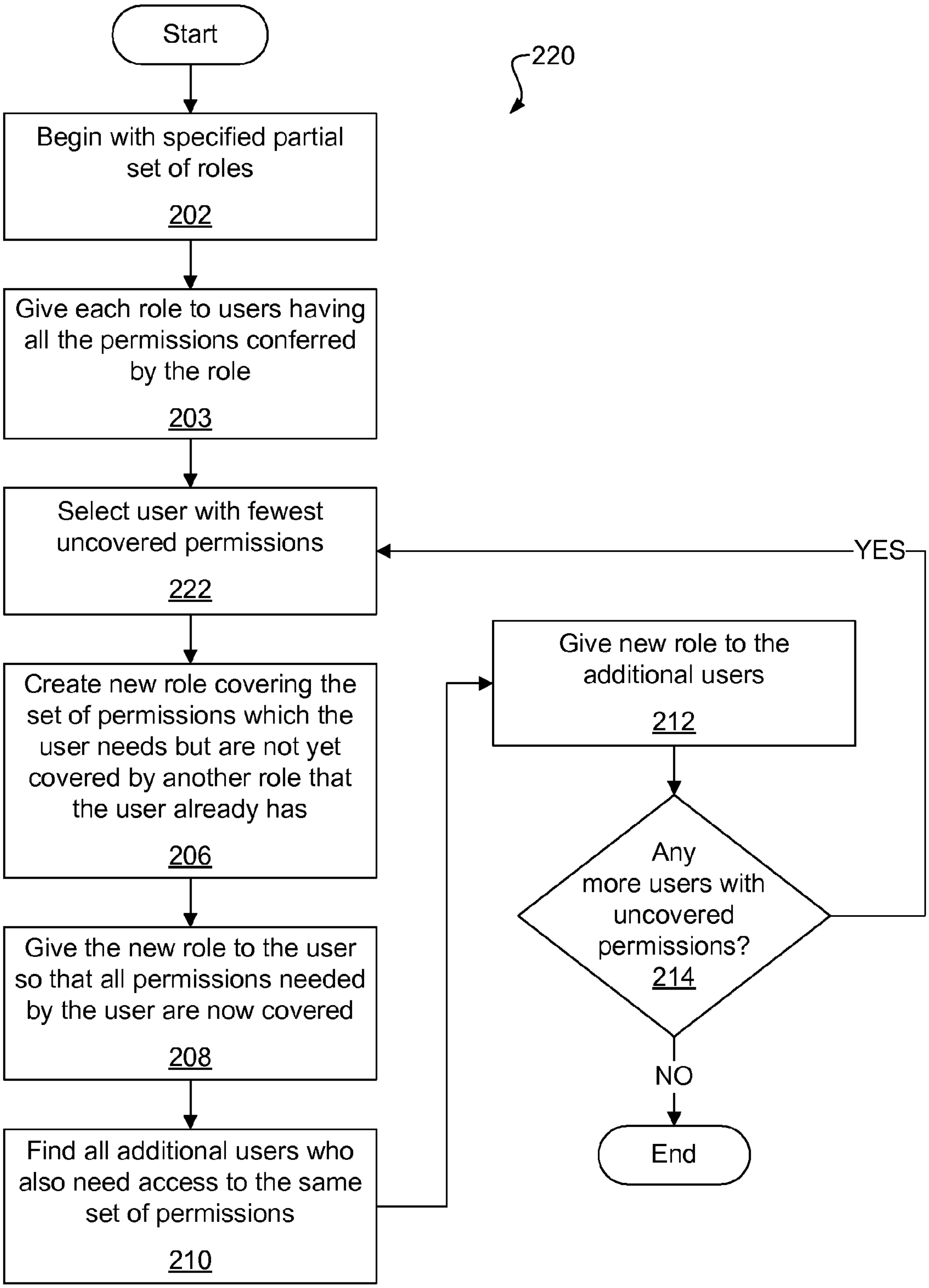

220
Start
Begin with specified partial set of roles
202
Give each role to users having all the permissions conferred by the role
203
Select user with fewest uncovered permissions
222
Create new role covering the set of permissions which the user needs but are not yet covered by another role that the user already has
206
Give the new role to the user so that all permissions needed by the user are now covered
208
Find all additional users who also need access to the same set of permissions
210
Give new role to the additional users
212
Any more users with uncovered permissions?
214
YES
NO
End

Fig. 2B

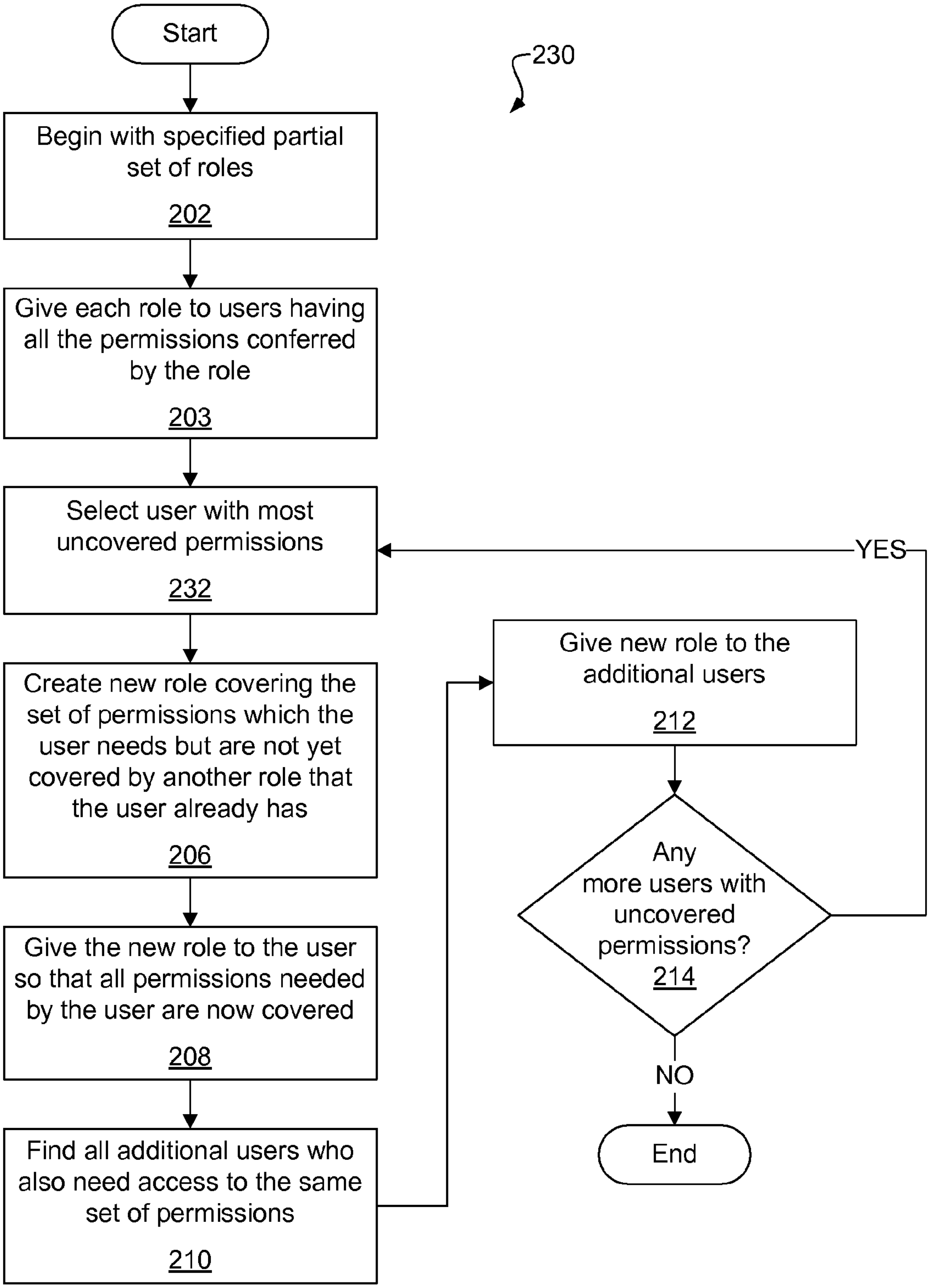

230
Start
Begin with specified partial set of roles
202
Give each role to users having all the permissions conferred by the role
203
Select user with most uncovered permissions
232
Create new role covering the set of permissions which the user needs but are not yet covered by another role that the user already has
206
Give the new role to the user so that all permissions needed by the user are now covered
208
Find all additional users who also need access to the same set of permissions
210
Give new role to the additional users
212
Any more users with uncovered permissions?
214
YES
NO
End

Fig. 2C

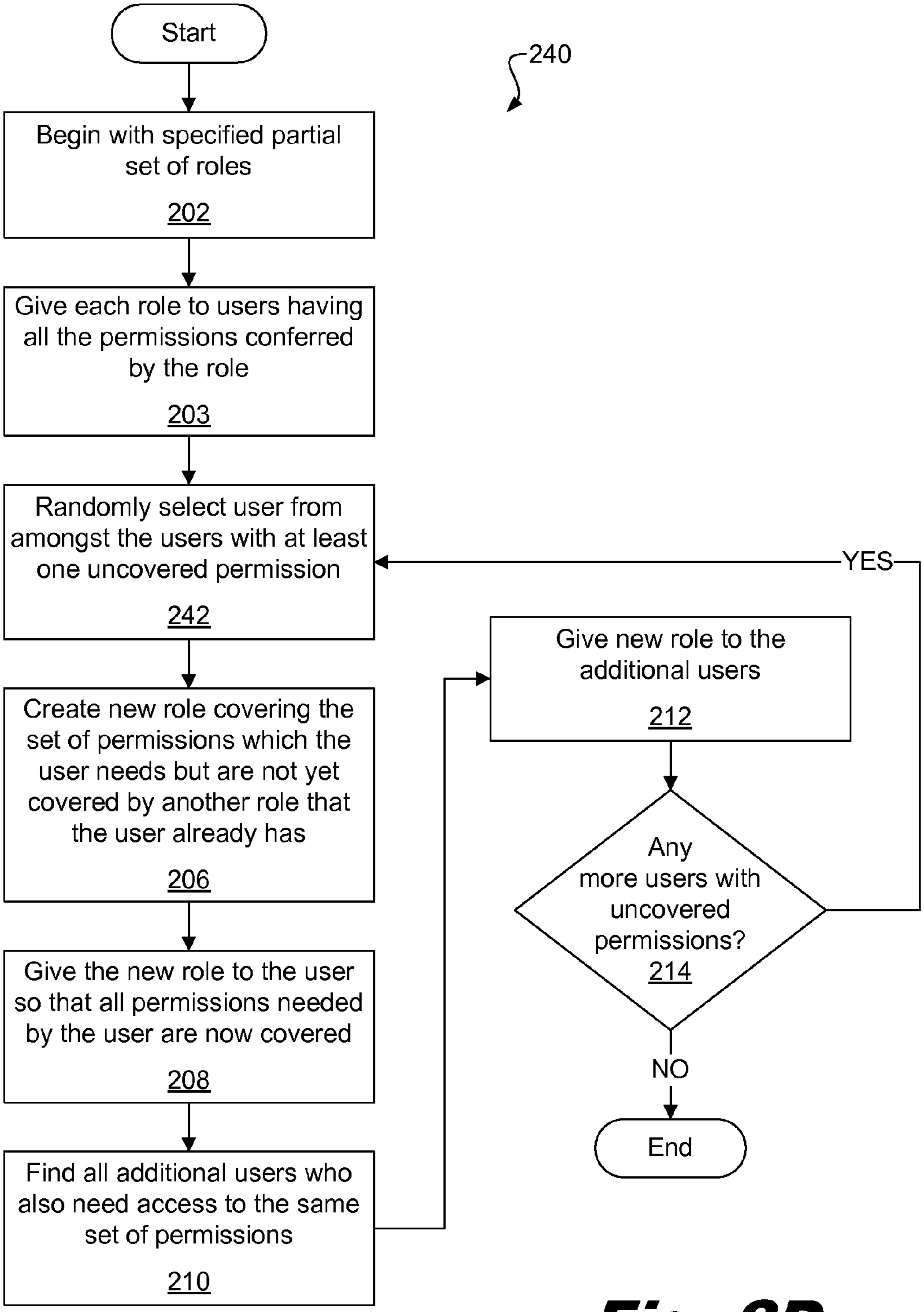

240
Start
Begin with specified partial set of roles
202
Give each role to users having all the permissions conferred by the role
203
Randomly select user from amongst the users with at least one uncovered permission
242
Create new role covering the set of permissions which the user needs but are not yet covered by another role that the user already has
206
Give the new role to the user so that all permissions needed by the user are now covered
208
Find all additional users who also need access to the same set of permissions
210
Give new role to the additional users
212
Any more users with uncovered permissions?
214
YES
NO
End

Fig. 2D

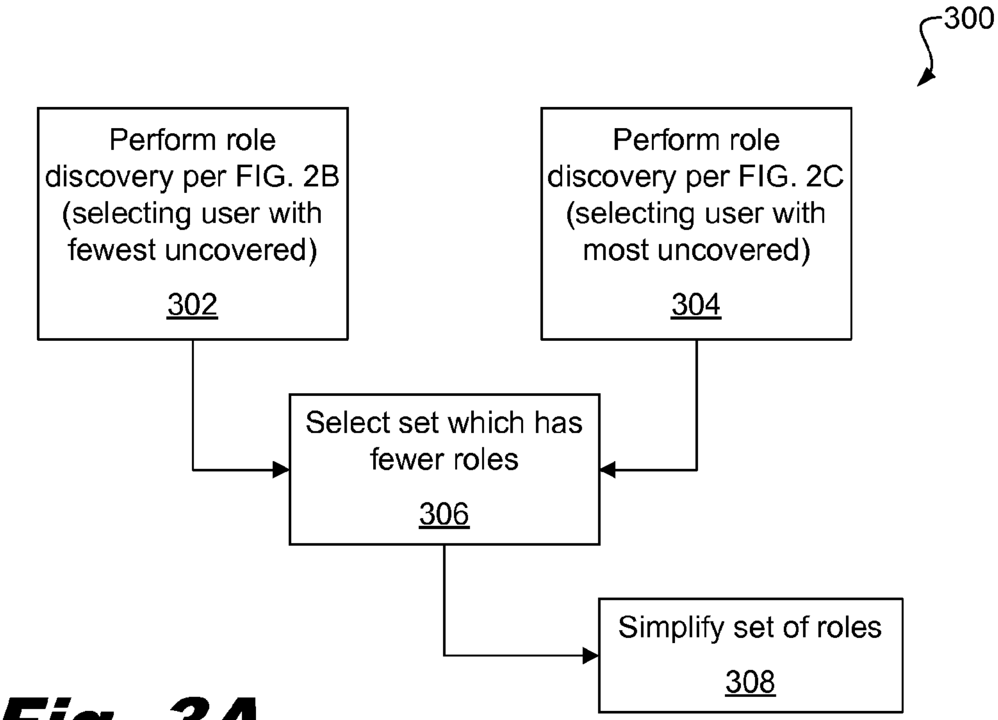

300
Perform role discovery per FIG. 2B (selecting user with fewest uncovered)
302
Perform role discovery per FIG. 2C (selecting user with most uncovered)
304
Select set which has fewer roles
306
Simplify set of roles
308

Fig. 3A

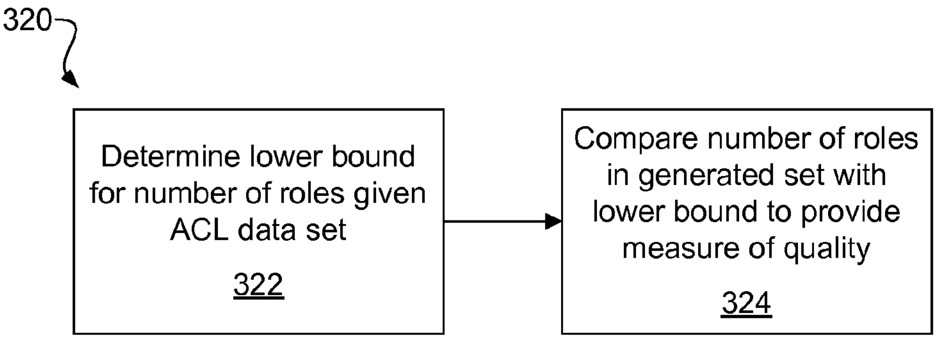

320
Determine lower bound for number of roles given ACL data set
322
Compare number of roles in generated set with lower bound to provide measure of quality
324

Fig. 3B

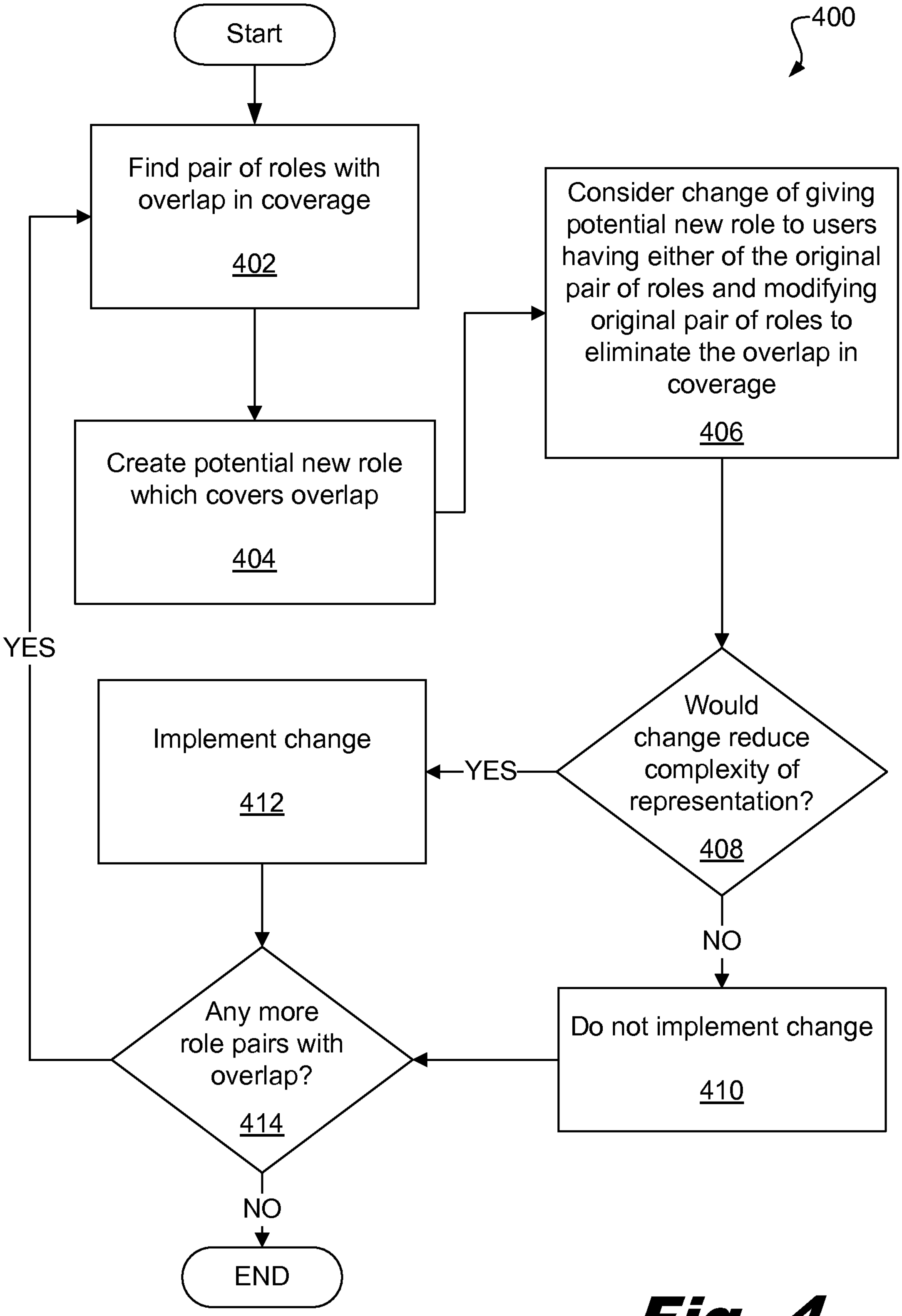

400
Start
Find pair of roles with overlap in coverage
402
Create potential new role which covers overlap
404
Consider change of giving potential new role to users having either of the original pair of roles and modifying original pair of roles to eliminate the overlap in coverage
406
Would change reduce complexity of representation?
408
YES
Implement change
412
NO
Do not implement change
410
Any more role pairs with overlap?
414
YES
NO
END

Fig. 4

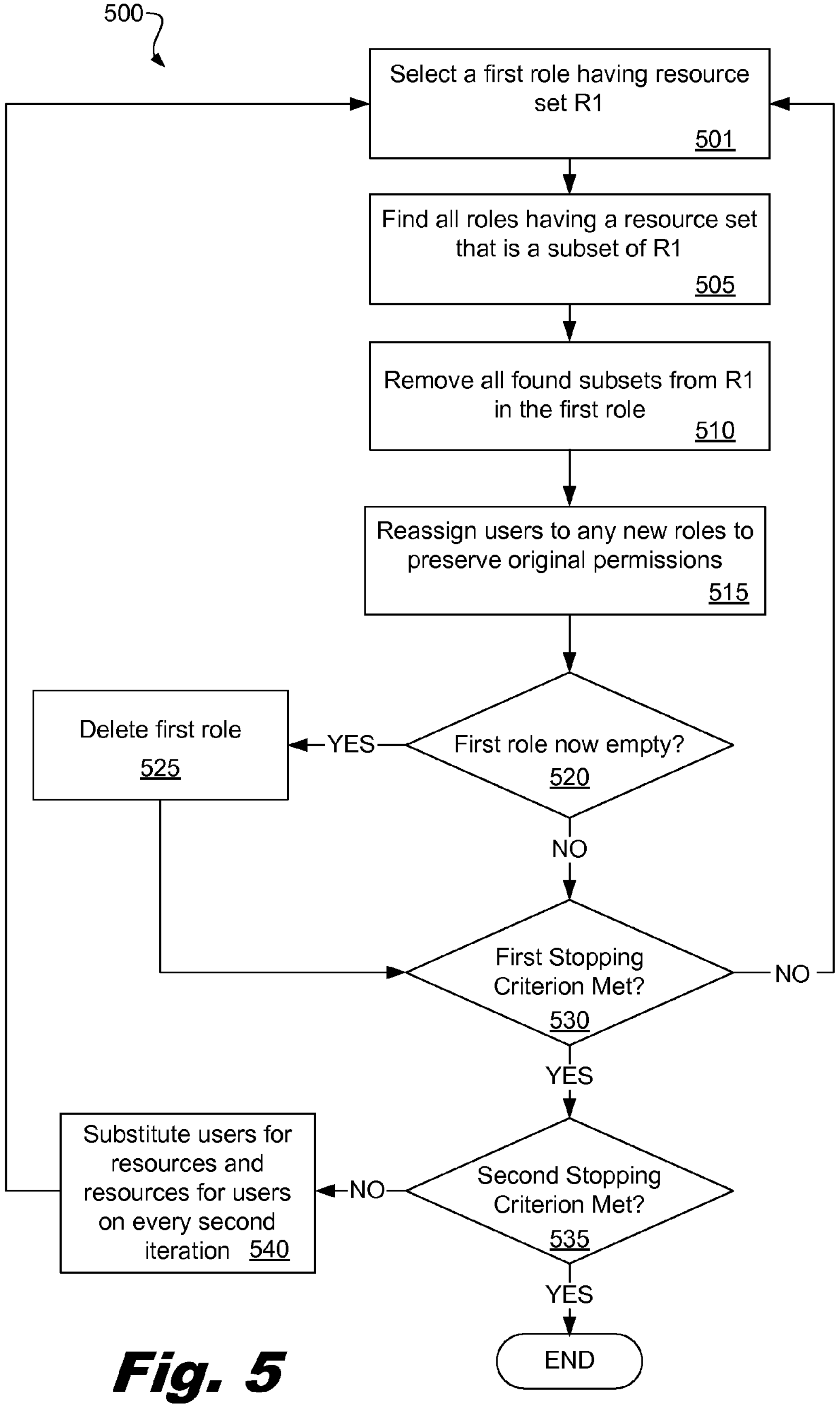

500
Select a first role having resource set R1
501
Find all roles having a resource set that is a subset of R1
505
Remove all found subsets from R1 in the first role
510
Reassign users to any new roles to preserve original permissions
515
First role now empty?
520
YES
Delete first role
525
NO
First Stopping Criterion Met?
530
NO
YES
Second Stopping Criterion Met?
535
NO
Substitute users for resources and resources for users on every second iteration
540
YES
END

Fig. 5

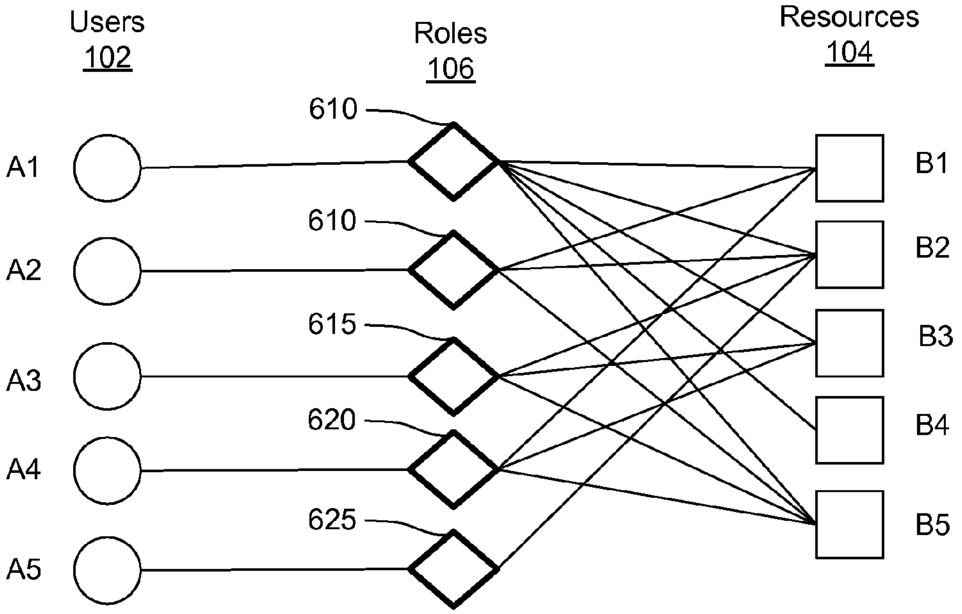

Users
102
Roles
106
Resources
104
610
610
615
620
625
A1
A2
A3
A4
A5
B1
B2
B3
B4
B5

Fig. 6A

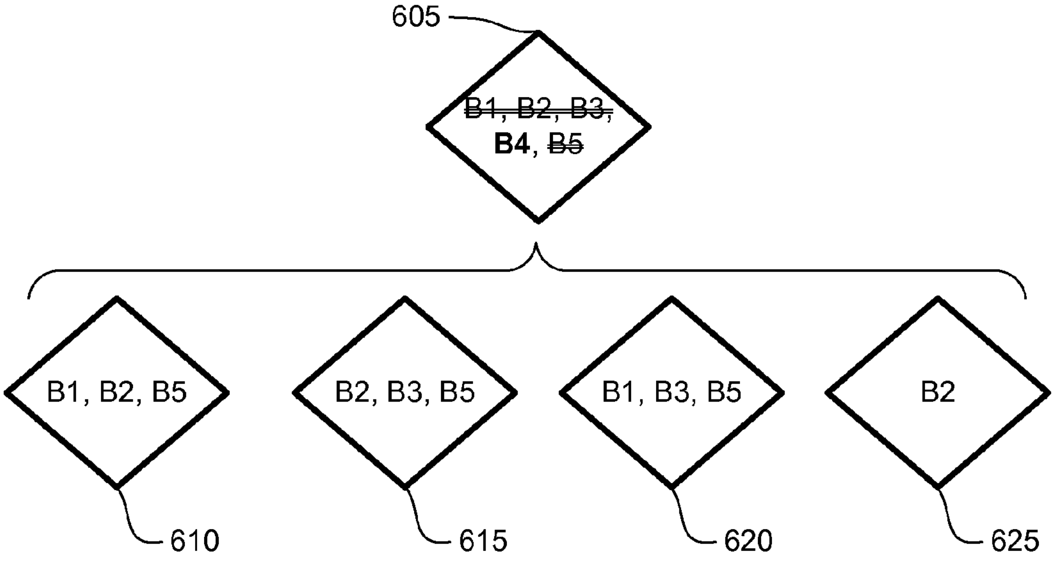

605
~~B1, B2, B3,~~
B4, ~~B5~~
B1, B2, B5
B2, B3, B5
B1, B3, B5
B2
610
615
620
625

Fig. 6B

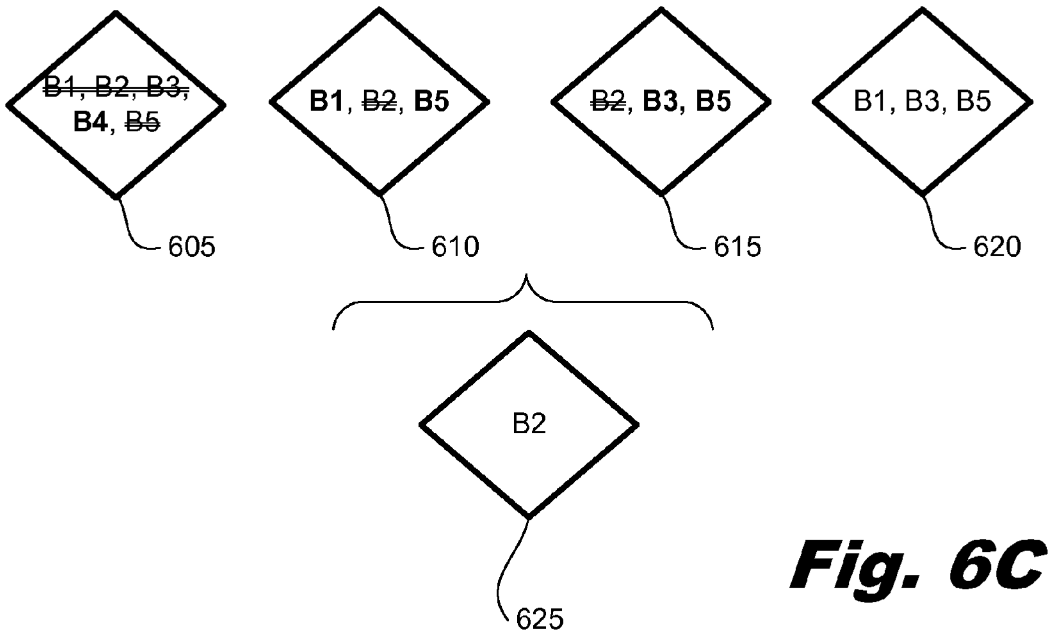

~~B1, B2, B3,~~
B4, ~~B5~~
605
B1, ~~B2~~, **B5**
610
~~B2~~, **B3, B5**
615
B1, B3, B5
620
B2
625

Fig. 6C

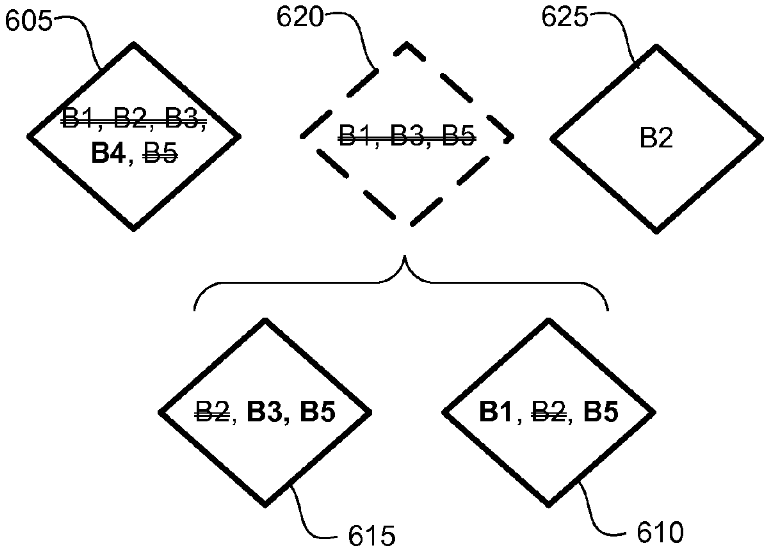

605
~~B1, B2, B3,~~
B4, ~~B5~~
620
~~B1, B3, B5~~
625
B2
~~B2~~, **B3, B5**
615
B1, ~~B2~~, **B5**
610

Fig. 6D

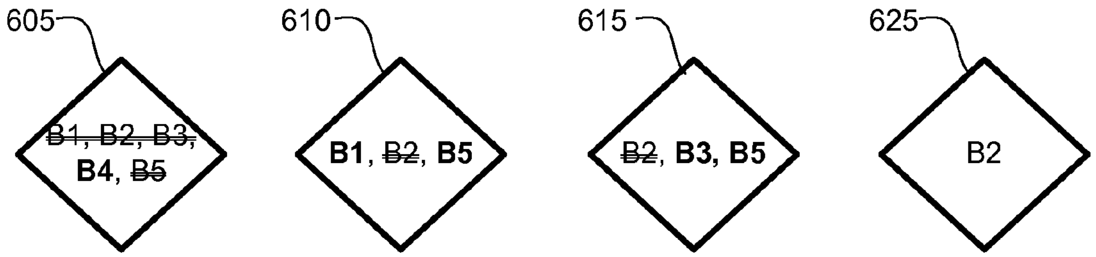

605
~~B1, B2, B3,~~
B4, ~~B5~~
610
B1, ~~B2~~, **B5**
615
~~B2~~, **B3, B5**
625
B2

Fig. 6E

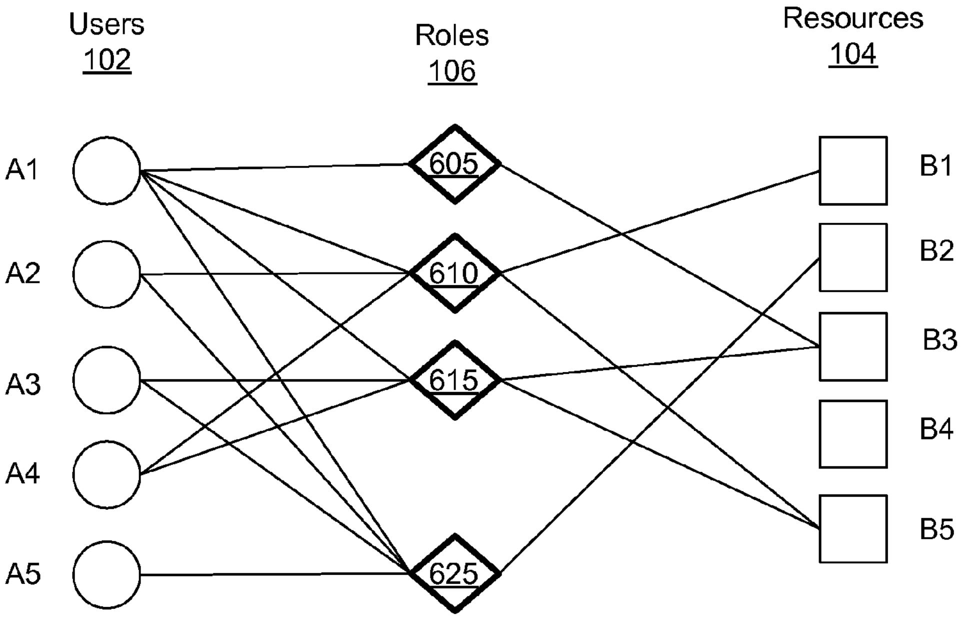

Users
102
Roles
106
Resources
104
A1
A2
A3
A4
A5
605
610
615
625
B1
B2
B3
B4
B5

Fig. 6F

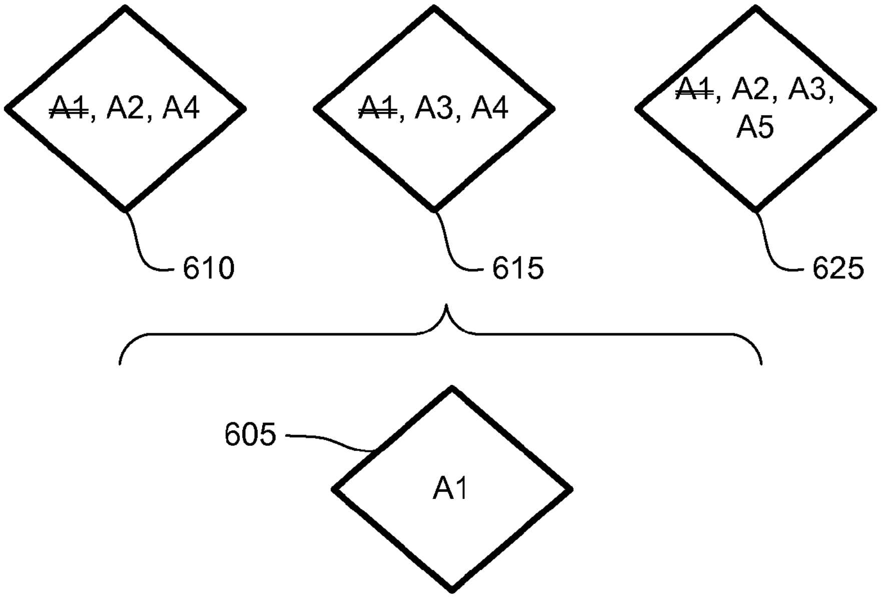

~~A1~~, A2, A4
~~A1~~, A3, A4
~~A1~~, A2, A3, A5
610
615
625
605
A1

Fig. 6G

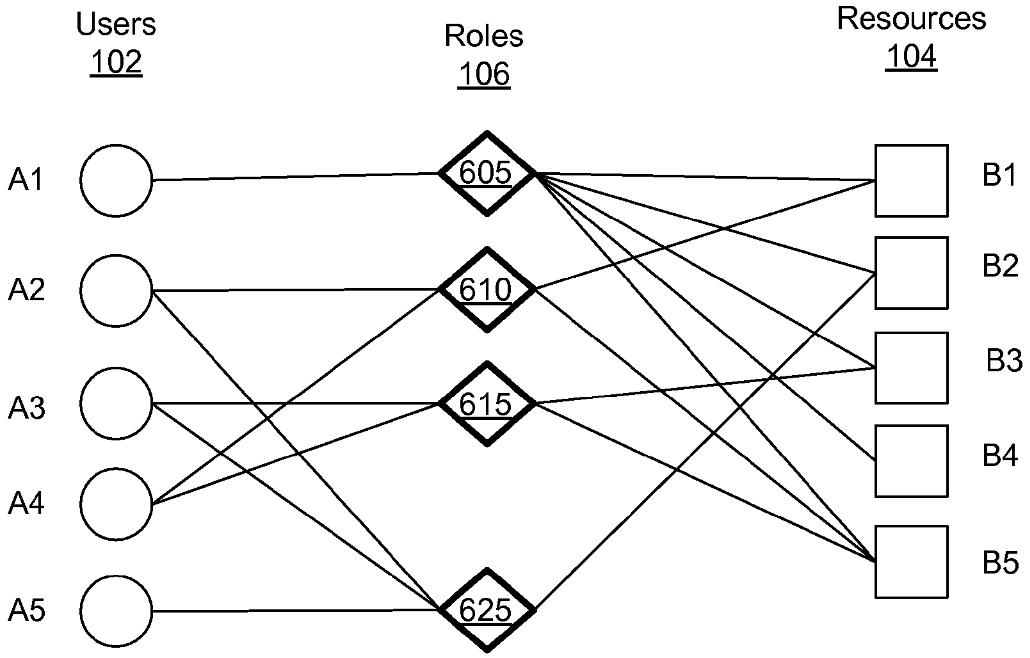

Users
102
Roles
106
Resources
104
A1
A2
A3
A4
A5
605
610
615
625
B1
B2
B3
B4
B5

Fig. 6H

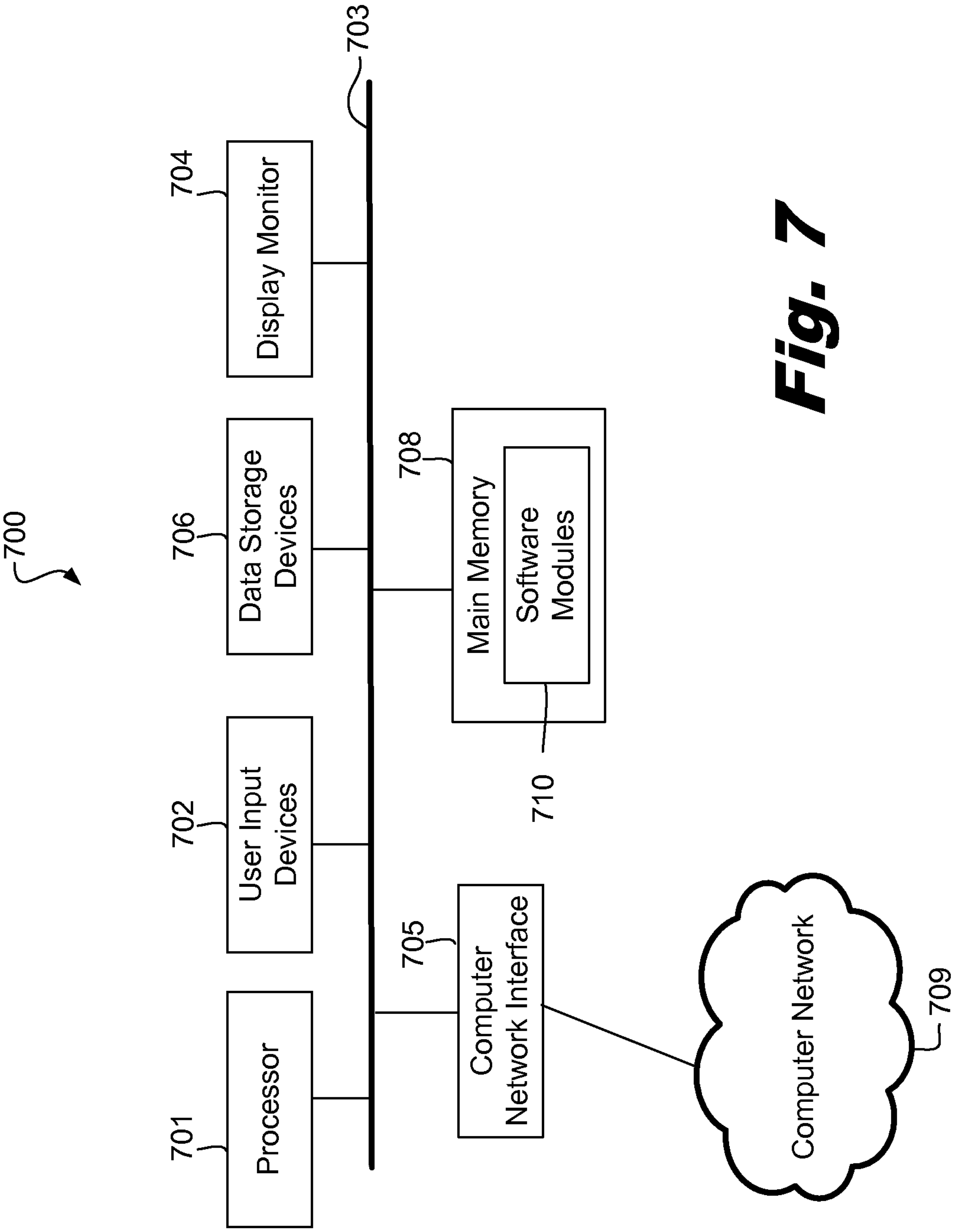

700
701
Processor
702
User Input Devices
706
Data Storage Devices
704
Display Monitor
703
705
Computer Network Interface
708
Main Memory
Software Modules
710
Computer Network
709

Fig. 7

COMPUTER-IMPLEMENTED METHOD FOR ROLE DISCOVERY AND SIMPLIFICATION IN ACCESS CONTROL SYSTEMS

RELATED APPLICATIONS

The present application is a continuation-in-part of U.S. patent application Ser. No. 11/888,381, filed on Jul. 31, 2007 by Robert Schreiber et al.

BACKGROUND

The present application relates generally to access control systems and more particularly to role discovery and simplification in access control systems.

In a simple access control system, access control lists (ACLs) are used. An ACL lists the user accounts (users) that have permission to use a given resource. The resource may be a file, or a network machine (with an internet protocol address), or a service provided by a port on a network machine, for example.

Such a set of ACLs may have a very large number of entries. As a simple example, if one thousand users each had permission to use one thousand different resources, then the ACL set would have a total of one million (one thousand multiplied by one thousand) entries. As the number of users and the number of resources grow, the size of this representation becomes extremely large and unwieldy. It becomes difficult to maintain, to check, to store, to present to an administrator, and to visualize on a graphics display. Ultimately, it becomes difficult, expensive, and error-prone to manage.

One way to reduce the size of the representation of the access permission is to utilize role-based access control (RBAC). In an RBAC system, a new kind of entity, the role, is introduced. Herein, a role may be defined as a set of permissions. Users may have or be assigned roles. A given role confers to its users permission to use certain resources.

In order to migrate from using a set of ACLs to using RBAC, an appropriate set of roles need to be discovered from the ACL data. The present application relates to a computer-implemented method of role discovery in access control systems.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings illustrate various embodiments of the principles described herein and are a part of the specification. The illustrated embodiments are merely examples and do not limit the scope of the claims.

FIGS. **1**A-**1**F are schematic diagrams depicting a simple example which is used for purposes of discussing embodiments of the present invention. More particularly, FIG. **1**A is a diagram showing a bipartite relationship between vertices of a first type representing users A**1**-A**4** and vertices of a second type representing resources B**1**-B**5**. FIG. **1**B is a diagram with emphasis on user A**1** and its permissions. FIG. **1**C is a diagram showing the introduction of role C**1**, and the assignment of role C**1** to user A**1**. FIG. **1**D is a diagram with emphasis on user A**4** and its permissions. FIG. **1**E is a diagram showing the assignment of role C**1** to user A**4**. FIG. **1**F is a diagram showing the assignment of roles C**2** and C**3** to users A**2** and A**3**, respectively.

FIG. **2**A is a flow chart of a computer-implemented procedure for role discovery in access control systems where a predetermined algorithm is used to select a next user in accordance with an embodiment of the invention.

FIG. **2**B is a flow chart of a computer-implemented procedure for role discovery in access control systems where a user with fewest uncovered permissions is selected as the next user in accordance with an embodiment of the invention.

FIG. **2**C is a flow chart of a computer-implemented procedure for role discovery in access control systems where a user with the most uncovered permissions is selected as the next user in accordance with an embodiment of the invention.

FIG. **2**D is a flow chart of a computer-implemented procedure for role discovery in access control systems where a user is randomly selected from amongst the remaining users with one or more uncovered permissions in accordance with an embodiment of the invention.

FIG. **3**A is a flow chart of a computer-implemented procedure for role discovery in access control systems where multiple procedures are used independently for role discovery and a better set of roles is selected in accordance with an embodiment of the invention.

FIG. **3**B is a flow chart of a computer-implemented procedure for providing a quantitative measure of quality for a generated set of roles in accordance with an embodiment of the invention.

FIG. **4** is a flow chart of a computer-implemented procedure for reducing complexity in a set of roles by eliminating overlap between pairs of roles in accordance with an embodiment of the invention.

FIG. **5** is a flow chart of a computer-implemented heuristic procedure for simplifying a set of discovered roles.

FIGS. **6**A to **6**H are schematic diagrams showing an illustrative implementation of the heuristic procedure of FIG. **5** on an exemplary role set, according to one exemplary embodiment of the principles described herein.

FIG. **7** is a schematic diagram of an example computer system which may be used to execute the computer-implemented procedures for role discovery and simplification in accordance with an embodiment of the invention.

Throughout the drawings, identical reference numbers designate similar, but not necessarily identical, elements.

DETAILED DESCRIPTION

In some situations, it may be desirable to discover roles from a set of ACLs by representing users and the resources to which the users have been granted access as vertices in a bipartite graph. A greedy algorithm may then be used to map roles to users and resources in the bipartite graph such that each role is connected to a set of users and a set of resources by edges. This type of method may provide significant time-savings and feasibility advantages over a purely recursive algorithm that returns an exact solution to an RBAC conversion. However, in many cases the solution returned by a greedy algorithm may be overly complex.

Therefore, in response to this and other issues, the present specification discloses systems and methods wherein roles are discovered from a set of ACLs through a greedy bipartite graph algorithm and simplified by a heuristic reduction method applied to the discovered roles. These improvements may be advantageously incorporated to facilitate the efficient and effective discovery of roles from a set of ACLs and also in subsequent optimization or re-optimization of an RBAC system.

In the following description, for purposes of explanation, numerous specific details are set forth in order to provide a thorough understanding of the present systems and methods. It will be apparent, however, to one skilled in the art that the present systems and methods may be practiced without these specific details. Reference in the specification to "an embodiment," "an example" or similar language means that a particular feature, structure, or characteristic described in connection with the embodiment or example is included in at least that one embodiment, but not necessarily in other embodiments. The various instances of the phrase "in one embodiment" or similar phrases in various places in the specification are not necessarily all referring to the same embodiment.

Referring to FIG. **1**A, a schematic diagram is presented showing a bipartite relationship between vertices of a first type and vertices of a second type. In this example, the vertices of the first type are user accounts (users) **102**, labeled A**1**, A**2**, A**3**, and A**4**, and the vertices of the second type are resources **104**, labeled B**1**, B**2**, B**3**, B**4** and B**5**. Of course, in an actual network system employing an ACL set, the number of users and the number of resources may be much higher. Here, small numbers of users and resources are shown for purposes of simplified explanation.

Users may have permission to access one or more resources. In the diagram, these permissions are indicated by lines connecting users to resources. For example, user A**1** has permission to access resources B**1** and B**3**, user A**2** has permission to access resources B**1** and B**5**, and so on.

Referring to FIG. **2**A, a flow chart is shown of a computer-implemented procedure **200** for role discovery in access control systems where a predetermined algorithm is used to select a next user in accordance with an embodiment of the invention. Each role specifies a set of users and a corresponding set of permissions granted to each of the users in the set. Therefore, graphically, each role may be represented as a biclique covering of a set of vertices of a first type that are indicative of users and a set of vertices of a second type that are indicative of permissions to those users.

Optional first two steps are shown in which a specified partial set of roles may be given at the beginning of the procedure (block **202**) and each role is given to users having all permissions conferred by the role (block **203**). For example, the partial set of roles may be specified by a system administrator. If any user's set of permissions is a superset of the permissions for any one role, that user may be assigned to that role, and the corresponding edges from the bipartite graph may be removed. Role discovery is then done on the remaining edges in the graph. In other words, if a partial set of roles is provided, then the subsequent steps may be utilized to extend the set of roles so as to cover the remaining uncovered permissions. Alternatively, these steps **202** and **203** may be skipped in cases where no such partial set of roles is specified.

In block **204**, a next user is selected according to a predetermined algorithm. Various predetermined algorithms may be applied to select the next user.

In a first embodiment, the predetermined algorithm may be to select the user with fewest uncovered permissions remaining (not counting those users whose permissions are already all covered by roles). This embodiment is shown with specificity in the procedure **220** of FIG. **2**B, where block **222** specifying selection of a user with the fewest uncovered permissions is substituted for block **204**. In the example shown in FIG. **1**A, users A**1**, A**2** and A**4** each have two permissions, while user A**3** has three permissions. Assuming all these permissions are uncovered, then this specific algorithm may select user A**1** (or user A**2** or A**4**) as its two uncovered permissions is among the fewest.

In a second embodiment, the predetermined algorithm may be to select the user with the most uncovered permissions remaining (not counting those users whose permissions are already all covered by roles). This embodiment is shown with specificity in the procedure **230** of FIG. **2**C, where block **232** specifying selection of a user with the most uncovered permissions is substituted for block **204**. In the example shown in FIG. **1**A, users A**1**, A**2** and A**4** each have two permissions, while user A**3** has three permissions. Assuming all these permissions are uncovered, then this specific algorithm may select user A**3** as its three uncovered permissions is the most.

In a third embodiment, the predetermined algorithm may randomly select a next user from the remaining users with at least one uncovered permission (not counting those users whose permissions are already all covered by roles). This embodiment is shown with specificity in the procedure **240** of FIG. **2**D, where block **242** specifying random selection is substituted for block **204**. In the example shown in FIG. **1**A, assuming users A**1**-A**4** each have at least one uncovered permission, then this specific algorithm may randomly select from amongst these four users. On the other hand, if user A**1** had all of its permissions already covered by a role or roles, then this specific algorithm would randomly select from amongst the group of users including users A**2**, A**3** and A**4**, but not A**1**.

In block **206**, a new role is created where the new role covers the set of permissions which the selected user still needs in that they are not yet covered by any other role that the user has. For example, consider FIG. **1**A, assuming the case where none of the permissions shown have been covered so far, and further that the selected user (per block **204**) is user A**1**. As emphasized in FIG. **1**B, user A**1** has permission to access resources B**1** and B**3**. Hence, in this example, a new role would be created to cover permissions to access resources B**1** and B**3**. Such a new role, labeled C**1** is shown in FIG. **1**C. As seen, role C**1** provides permission to access resources B**1** and B**3**.

Per block **208**, the new role is given to the selected user. Since the new role covers all the previously uncovered permissions of the selected user, the selected user now has all its permissions covered by roles. For example, FIG. **1**C shows by the line between user A**1** and role C**1** that user A**1** is given role C**1**. Further, it is shown that all the permissions of user A**1** are now covered by roles (in this case, by role C**1**).

In block **210**, all additional users who also need access to the same set of permissions are found. In other words, all users who also have the same uncovered permissions are found. In our example, as emphasized in FIG. **1**D, user A**4** also has uncovered permissions to resources B**1** and B**3**. Hence, user A**4** is an additional user who also needs access to the same set of permissions.

Per block **212**, the new role is also given to the additional users (found per block **210**). For example, FIG. **1**E shows by the line between user A**4** and role C**1** that user A**4** is also given role C**1**.

Per block **214**, a determination may then be made as to whether there are any more users with uncovered permissions.

If there are one or more users with uncovered permissions remaining, then the procedure loops back to block **204** and selects the next user according to the predetermined algorithm. For example, FIG. **1**F shows diagrammatically the addition of the new role C**2** to cover the permissions of the user A**2**, and the addition of the new role C**3** to cover the permissions of the user A**3**.

On the other hand, if there are no more users with uncovered permissions remaining, then the procedure may end as all the bipartite permissions have been covered by roles.

FIG. **3**A is a flow chart of a computer-implemented procedure **300** for role discovery in access control systems where multiple procedures are used independently for role discovery and a better set of roles is selected in accordance with an embodiment of the invention.

Per blocks **302** and **304**, role discovery may be performed by two (or more) different automated techniques. In the particular example shown, role discovery may be performed **302** per FIG. **2**B, where the computer-implemented procedure **220** includes selecting **222** a next user to be a user which has the fewest uncovered permissions remaining. Role discovery may also be performed **304** per FIG. **2**C, where the procedure **230** includes selecting **232** a next user to be a user which has the most uncovered permissions remaining. Thereafter, the set of roles which has the fewer roles may be selected per block **306**. Alternatively, other criteria may be used to determine the preferable set of roles to select.

In addition, per block **308**, the automatically discovered set of roles may be simplified. One or more computer-implemented procedures may be used to reduce complexity of the set of roles. One particular complexity-reducing procedure **400** removes overlap between roles and is discussed further below in relation to FIG. **4**. Another particular complexity-reducing procedure **500** proposes roles that are over-approximations and is discussed further below in relation to FIG. **5**.

FIG. **3**B is a flow chart of a computer-implemented procedure **320** for providing a quality measure for a generated set of roles in accordance with an embodiment of the invention. This procedure **320** may be applied, for example, to the set of roles determined by the procedure **300** of FIG. **3**A.

As shown per block **322**, a determination may be made as to a lower bound L for the number of roles given an ACL data set. The determination may be made by finding a set consisting of L individual permissions (a single user and single resource that the user has permission to access) with the property that for any two of these individual permissions, they cannot both be conferred by any one role. In other words, the set found contains only mutually independent permissions. A pair of permissions is mutually independent if they relate to two distinct users and to two distinct resources, and either or both of these two users does not have permission to use both of these two resources.

Thereafter, per block **324**, the number of roles in the discovered (or otherwise generated) set of roles may be compared to the lower bound. The gap between the number of roles in the set and the lower bound provides a quantitative measure of the quality of the set of roles, such that a smaller gap provides a higher level of confidence in the generated set of roles.

FIG. **4** is a flow chart of a computer-implemented procedure **400** for reducing complexity in a set of roles by removing overlap between pairs of roles in accordance with an embodiment of the invention. This procedure **400** may be used, for example, as part of block **308** in FIG. **3** to simplify the set of discovered roles.

In block **402**, a pair of roles with overlapping coverage (i.e. overlapping permissions to access resources) is found. For example, consider the pair of roles C7 and C8, where C7 covers (i.e. gives permission to access) resources B**11** through B**30**, and C**8** covers resources B**16** through B**35**. The original roles in this example are depicted in FIG. **7**A. Here, the overlapping coverage (overlap in permissions) is to resources B**16** through B**30**.

Per block **404**, a potential new role is created which covers overlap in permissions. In our example, potential new role CX is created which covers resources B**16** through B**30**.

In block **406**, consideration is given to making a change to the role set by adding the new potential role, giving the new potential role to users having either of the original pair of roles, and modifying the original pair of roles to eliminate the overlap in coverage. In our example, the change would involve adding role CX which covers resources B**16** through B**30**, giving role CX to users having either role C**7** or C**8**, and modifying roles C**7** and C**8** to eliminate the overlapping coverage of resources B**16** through B**30**. After the modification, role C**7** would only cover resources B**11** through B**15**, and role C**8** would only cover resources B**31** through B**35**. The modified roles in this example are shown in FIG. **7**B.

Per block **408**, a determination may then be made as to whether the change being considered would reduce the complexity of the RBAC representation. In one embodiment, the complexity of the RBAC representation may be calculated as the total number of "edges" between users **102** and roles **106**, plus the total number of "edges" between roles **106** and resources **104**, plus the total number of roles **106**. In other words, this measure sums over all the roles the summand comprising the number of users who have each role and the number of resources granted by each role, and then adds the number of roles. This measure gives a number of entities that must be maintained by the system.

If the change being considered would not reduce the complexity of the representation, then, per block **410**, the change is not actually implemented. On the other hand, if the change being considered reduces the complexity of the representation, then, per block **412**, the change is implemented.

The procedure **400** then continues on by determining, per block **414**, whether or not there are any more role pairs with overlap that have yet to be analyzed per the above-discussed steps. If there are any more role pairs with overlap to be analyzed, then the procedure may loop back to block **402** so as to analyze these pairs to see if the representation may be further simplified. Otherwise, if there are no more role pairs with overlap to be analyzed, then the procedure may end.

Applicants have found that the above-discussed procedure **400** is often effective in reducing the size of an RBAC representation by a factor of two or more. Advantageously, reducing the size of the RBAC representation reduces the number of entities that are to be maintained by the system.

FIG. **5** is a flow chart of a computer-implemented procedure **500** for heuristically simplifying a set of roles obtained by the procedures of FIGS. **2**A-**2**D, **3**A-**3**B, and/or **4**. Specifically, the present procedure **500** may reduce complexity by reducing the number of edges between users and permissions and/or the number of total roles. The procedure **500** may be performed by, for example, a computing device used to discover the set of roles. Alternatively, the present procedure **500** may be performed by any other computing device that may suit a particular embodiment. Additionally, the present procedure **500** may be stored as computer-readable code on at least one computer-readable medium such that a computing device executing the computer-readable code would perform at least the steps of the procedure **500**.

In block **501**, a first role is identified from within the body of previously determined roles. The role has a corresponding resource set R**1** that represents the set of resources for which any user connected to the first role has permission to access. The first role may be selected randomly, in accordance with an algorithm, or by any other means that may suit a particular application of the principles described herein.

In block **505**, all other roles having a resource set that is a subset of R**1** are found within the body of previously determined roles. In other words, every found role has a set of resources that are each present in R**1**, the resource set of the first role.

In block **510**, all found subsets are removed from R**1** in the first role. That is, every resource corresponding to the roles found in block **505** is removed from the resource set of the first role selected in block **501**. Of course, if no subsets of R**1** were found, no modification will be made to the first role.

In block **515**, users are reassigned to new roles as necessary to preserve the original permissions those users had, as reflected in the bipartite graph, prior to beginning the heuristic procedure **500**.

Per block **520**, a determination may then be made as to whether the first role is now empty. Such will be the case in situations where the entire set of R**1** is represented by one or more subsets of the resource sets found per block **505**. If the first role is found to be empty, the first role is deleted per block **525**, and the number of total roles in the system is consequently reduced by one.

In block **530**, a determination may be made as to whether a first stopping criterion has been met. For example, in certain embodiments the first stopping criterion may include a determination that no additional role exists wherein the set of resources associated with that role are a subset of another role in the system. In other embodiments, the stopping criteria may include a threshold of elapsed time any other stopping criteria that may suit a particular application of the principles herein. If the first stopping criteria have not been met, flow is returned to block **505**, where blocks **501**, **505**, **510**, **515**, **520**, **525** and **530** are repeated until the first stopping criterion has been met.

If the first stopping criterion has been met per block **530**, a determination may then be made per block **535** as to whether a second stopping criterion has been met. If not, blocks **505** to **535** are repeated with the sets of user vertices substituted for the sets of resources vertices and vice versa on every other iteration per block **540**. Thus, in the new iteration, per block **501** a first role will be selected having user set U**1**, all roles having a user set that is a subset of U**1** will be found per block **505**, and all found subsets will be removed from U**1** in the first role per block **510**. Consequently, blocks **501** to **535** will be continuously repeated, with the sets of user vertices substituted for the sets of permissions vertices on every second iteration of the second stopping criterion being met per block **530**. This will continue until a determination has been made per block **535** that a second stopping criterion has been met. In certain embodiments, the second stopping criterion may include a set number of iterations of the first stopping criterion being met per block **530**. In other embodiments, the second stopping criterion may include a threshold amount of elapsed time, a desired level of convergence of the number of roles and/or edges in the system, and/or any other criteria that may be suitable according to a particular embodiment of the principles described herein.

FIGS. **6**A through **6**H illustrate one example of role reduction and simplification according to the process **500** of FIG. **5**. FIG. **6**A shows a set of users **102**, a set of resources **104**, and a set of previously discovered roles **106** that connect the users **102** to individual resources **104** according to permissions in an access control system. Again, the principles described herein are not limited to role discovery and simplification in an access control system. Rather, it is anticipated that the principles described herein may be applied to any situation in which a minimum biclique cover of a bipartite graph is sought.

In FIG. **6**B, each of the roles **605**, **610**, **615**, **620**, **625** of FIG. **6**A is shown with its corresponding set of resources. For example, role **605** has a resource set that includes resources B**1**, B**2**, B**3**, B**4**, and B**5**. In the present example, role **605** is selected per block **501** in FIG. **5**, and each of the remaining roles **610**, **615**, **620**, **625** is found per block **505**, due to the fact that each of the remaining roles **610**, **615**, **620**, **625** has a resource set that is a subset of the resource set of role **601**. Per block **510**, each of the resources in role **605** that is represented by one of the remaining roles **610**, **615**, **620**, **625** is removed from the resource set of role **605**, leaving role **605** with a permission set that only includes the single resource B**4**.

In the present example, the first stopping criteria is a determination that no roles remain that have a resource set that is a subset of another role. As this is not the case, the first stopping criterion has not been met per block **530**, and flow is returned to block **505**. As shown in FIG. **6**C, the resource set of role **625**—single resource B**2**—is a subset of the resource set of both role **610** and role **615**. Therefore, through consecutive iterations of blocks **501** to **530**, resource B**2** will be removed from both of roles **610**, **615**.

As shown in FIG. **6**D, newly modified roles **610**, **615** are both subsets of role **620**. Therefore, successive iterations of blocks **501** to **530** will remove the resource sets of roles **610**, **615** from that of role **620**, leaving role **620** empty. Role **620** will be subsequently deleted, thereby reducing the number of roles in the system by one.

FIG. **6**E shows the remaining four roles **605**, **610**, **615**, **625** as they have been modified once the first stopping criterion has been met per block **530**.

FIG. **6**F shows the assignation of users **102** to the newly modified roles **605**, **610**, **615**, **625** to preserve the original user-resource permissions per block **515**.

If the second stopping criterion has not been met per block **535**, blocks **505** to **535** will be repeated with user sets substituted for resource sets and vice versa. FIGS. **6**G and **6**H show how this may proceed.

In FIG. **6**G, each of the roles **605**, **610**, **625** shown in FIGS. **6**E and **6**F is shown with its corresponding set of users. For example, role **605** contains a user set of single user A**1**. Because role **605** contains a user set that is a subset of each of the remaining roles **610**, **615**, **625**, single user A**1** will be removed from the user sets of these remaining roles **610**, **615**, **625** through three successive iterations of blocks **501** to **530**, after which the first stopping criterion will have been met per block **530**.

FIG. **6**H shows the assignation of resources **104** to the newly modified roles **605**, **610**, **615**, **625** to preserve the original user-resource permissions per block **515**. If the second stopping criterion has been met per block **535**, the process **500** of FIG. **5** will end here. Otherwise, the heuristic process **500** will repeat again as previously described.

FIG. **7** is a schematic diagram of an example computer system or apparatus **700** which may be used to execute the computer-implemented procedures for role discovery and role reduction in accordance with an embodiment of the invention. The computer **700** may have fewer or more components than illustrated. The computer **700** may include a processor **701**, such as those from the Intel Corporation or Advanced Micro Devices, for example. The computer **700** may have one or more buses **703** coupling its various components. The computer **700** may include one or more user input devices **702** (e.g., keyboard, mouse), one or more data storage devices **706** (e.g., hard drive, optical disk, USB memory), a display monitor **704** (e.g., LCD, flat panel monitor, CRT), a computer network interface **705** (e.g., network adapter, modem), and a main memory **708** (e.g., RAM).

In the example of FIG. **10**, the main memory **708** includes software modules **710**, which may be software components to perform the above-discussed computer-implemented procedures. The software modules **710** may be loaded from one or more data storage devices **706** to the main memory **708** for execution by the processor **701**. Specifically, the software modules **710** may include one or more modules of computer readable code for performing the tasks of role discovery and simplification according to the principles described herein. The computer network interface **705** may be coupled to a computer network **709**, which in this example includes the Internet.

In the above description, numerous specific details are given to provide a thorough understanding of embodiments of the invention. However, the above description of illustrated embodiments of the invention is not intended to be exhaustive or to limit the invention to the precise forms disclosed. One skilled in the relevant art will recognize that the invention can be practiced without one or more of the specific details, or with other methods, components, etc. In other instances, well-known structures or operations are not shown or described in detail to avoid obscuring aspects of the invention. While specific embodiments of, and examples for, the invention are described herein for illustrative purposes, various equivalent modifications are possible within the scope of the invention, as those skilled in the relevant art will recognize.

These modifications can be made to the invention in light of the above detailed description. The terms used in the following claims should not be construed to limit the invention to the specific embodiments disclosed in the specification and the claims. Rather, the scope of the invention is to be determined by the following claims, which are to be construed in accordance with established doctrines of claim interpretation.

What is claimed is:

1. A method of migrating an electronic access control system for a number of available electronic resources from an Access Control List to a Role-Based Access Control (RBAC) system, the method comprising, with a processor:

discovering a plurality of roles, wherein each of said roles is a biclique covering of a set of vertices of a first type and a corresponding set of vertices of a second type;

selecting a first role in said plurality and finding all roles in said plurality that have a set of vertices of said second type that is a subset of said set of vertices of said second type in said first role;

removing each of said subsets from said set of vertices of said second type corresponding to said first role;

reassigning said vertices of said first type to said roles such that original associations between said vertices of said first type and said vertices of said second type are maintained; and

performing access control for the available electronic resources using said roles and vertices in an RBAC system.

2. The method of claim **1**, further comprising:

determining if said first role is empty after said subsets are removed from said set of vertices of said second type corresponding to said first role; and

deleting said first role if said removal leaves said first role empty.

3. The method of claim **1**, further comprising:

repeating said selecting, finding, removing, and reassigning until a second stopping criterion is met; and

substituting said vertices of said second type for said vertices of said first type and said vertices of said first type for said vertices of said second type every other time a first stopping criterion is met.

4. The method of claim **3**, wherein said first stopping criterion comprises at least one of: a threshold of elapsed time and a determination that that no additional role exists having a set of vertices of said second type that is a subset of a set of vertices of said second type in another role.

5. The method of claim **3**, wherein said second stopping criterion comprises at least one of: a threshold number of iterations, a threshold amount of elapsed time, and a threshold degree of convergence of a number of said roles.

6. The method of claim **1**, wherein said vertices of said first type correspond to individual users and said vertices of said second type correspond to resources for which access is granted to said users, as specified by said roles.

7. A system for implementing a Role-Based Access Control (RBAC) system for a number of electronic resources, the system comprising:

digital memory configured to store at least a plurality of vertices of a first type, a plurality of vertices of a second type, and a plurality of biclique roles associating sets of said vertices of said first type with sets of said vertices of said second type; and

at least one processor in communication with said memory, said processor being configured to:

select a first role in said plurality of biclique roles and find all roles in said plurality of biclique roles that have a set of vertices of said second type that is a subset of said set of vertices of said second type in said first role;

remove each of said subsets from said set of vertices of said second type corresponding to said first role;

reassign said vertices of said first type to said roles such that original associations between said vertices of said first type and said vertices of said second type are maintained; and

perform access control for the available electronic resources using said roles and vertices in an RBAC system.

8. The system of claim **7**, wherein said processor is further configured to:

determine if said first role is empty after said subsets are removed from said set of vertices of said second type corresponding to said first role; and

delete said first role if said removal leaves said first role empty.

9. The system of claim **7**, wherein said processor further configured to:

repeat said selecting, finding, removing, and reassigning until a second stopping criterion is met; and

substitute said vertices of said second type for said vertices of said first type and said vertices of said first type for said vertices of said second type every other time a first stopping criterion is met.

10. The system of claim **8**, wherein said first stopping criterion comprises at least one of: a threshold of elapsed time and a determination that that no additional role exists having a set of vertices of said second type that is a subset of a set of vertices of said second type in another role.

11. The system of claim **9**, wherein said second stopping criterion comprises at least one of: a threshold number of iterations, a threshold amount of elapsed time limit, and a threshold degree of convergence of a number of said roles.

12. The system of claim **7**, wherein said vertices of said first type correspond to users and said vertices of said second type correspond to resources for which access is granted to certain of said users, as specified by said roles.

13. A computer program product comprising:

a non-transitory computer readable device having computer usable program code embodied therewith, the computer usable program code comprising:

computer usable program code configured to discover a plurality of roles, wherein each of said roles is a biclique covering of a set of vertices of a first type and a corresponding set of vertices of a second type;

computer usable program code configured to select a first role in said plurality and find all roles in said plurality that have a set of vertices of said second type that is a subset of said set of vertices of said second type in said first role;

computer usable program code configured to remove each of said subsets from said set of vertices of said second type corresponding to said first role;

computer usable program code configured to reassign said vertices of said first type to said roles such that original associations between said vertices of said first type and said vertices of said second type are maintained; and

computer usable program code configured to perform access control for the available electronic resources using said roles and vertices in an RBAC system.

14. The computer program product of claim **13**, further comprising:

computer usable program code configured to determine if said first role is empty after said subset is removed from said set of vertices of said second type corresponding to said first role; and

computer usable program code configured to delete said first role if said removal leaves said first role empty.

15. The computer program product of claim **13**, further comprising:

computer usable program code configured to repeat said selecting, finding, removing, and reassigning steps until a first stopping criterion is met;

computer usable program code configured to substitute said vertices of said first type with said vertices of said second type in said finding, removing, and adding steps every other time said first criterion is met.

16. The computer program product of claim **13**, further comprising:

computer usable program code configured to create a new role covering a set of permissions associated with a user account of said first type that are not yet covered with another role associated with said user account.

17. The computer program product of claim **16**, further comprising:

computer usable program code configured to assign said new role to said user account so that all permissions needed for said user account are covered.

18. The computer program product of claim **17**, further comprising:

computer usable program code configured to find other user accounts who need access to said permissions.

19. The computer program product of claim **18**, further comprising:

computer usable program code configured to assign said new role to said other user accounts.

20. The computer program product of claim **16**, wherein vertices of said first type are user accounts.

* * * * *